Effects of Manure Application Timing on Maize (*Zea Mays* L.) Yields for Subsistence Farming in Western Kenya

An Honors Thesis Proposal

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Introduction

In 2000, the United Nations launched the Millennium Development Goals with efforts of creating a strategic plan for addressing problems such as health, education, equality, and environmental sustainability in countries classified as developing, to be realized by 2015 (United Nations, 2004). The first of the eight goals is to eradicate extreme poverty and hunger; specifically the targets are to: 1) halve, from 1990 to 2015, the proportion of people whose income is less than one dollar a day, and 2) halve, from 1990 to 2015, the proportion of people who suffer from hunger. In 1990, 47% of Sub-Saharan Africa's (SSA) population lived on $1 a day (World Bank, 2007). This is based on PPP: Purchasing Power Parity, in which both exchange rate and living standards are taken into account. By 1999, this had decreased to 46% of SSA's population living on $1 a day and to 41% by 2004 (World Bank, 2007). Kenya is located in East Africa and is part of SSA. In 1997, 23% of Kenya's population lived on $1 a day (PPP), but 52% of the population lived under Kenya's national poverty line (World Bank, 2007). As of 2004 when a progress report was generated, it was reported that virtually no change had been observed in SSA with regard to the first of the two targets (UN, 2004).

In 1990, 72% of SSA's population lived in rural areas, and by 2006 it had decreased to 64%. In Kenya, 79% of the population lived in rural areas as of 2006 (World Bank, 2007). Both Kenya and SSA as a whole have experienced annual population growths between 2 and 3% between 1990 and 2006 (World Bank, 2007). However, as of 2004 food production had only increased by 7% in SSA and by 4% in Kenya compared to production in 2000 (World Bank, 2007). Furthermore, increased agricultural output is more a result of increased land area under cultivation rather than intensification. Land used for cereal production increased by almost 12% in SSA and by 15.5% in Kenya from 2000 to 2005 (World Bank 2007). In both SSA and Kenya, agricultural output is growing at rates lower than population growth and amount of land under cultivation. The land is becoming less efficient in producing food, which corresponds with increased food insecurities and poverty.

There are many causes for this dilemma, but poor soil and nutrient management, leading to poor soil structure and declining soil fertility, are major contributors. When comparing the climate and soil orders of SSA with temperate regions of the world, it is understandable that crop yields are lower on soils of the tropics primarily because they are highly weathered and have low inherent fertility. However, SSA soils have the capacity and ability to be productive, if managed correctly.

To examine one aspect of soil management by subsistence farmers in Kenya, the objective of this project will be to examine the effects of manure application timing on maize (*Zea mays* L.) yields, one of Kenya's staple foods. Specifically, a post-harvest manure application will be compared to a pre-planting manure application using six maize plots at four farm locations. The research location in Western Kenya is dominated by Nitisols, classified as deep, red friable soils (Kenya Soil Survey, 2004). These soils are clayey and possess an argillic B-horizon (ISEM, 2007). Due to their highly weathered characteristics, these soils are slightly acidic and finely textured, which should help minimize N volatilization. However, high temperatures and traditional broadcast applications of manure fertilizers would result in increased risk of volatilization. It is hypothesized that, because of volatilization potential, plots receiving a pre-planting manure application will produce higher maize yields than plots receiving an earlier, post-harvest application.

Recent Work and Justification

Basic Concepts

Maize is classified as tall-growing, cereal grass that is a monecious monocot (Smith 1995). Modern maize plants have one main culm containing 20 leaves. A plant typically has one lateral branch, but occasionally more, that terminates in an ear. Water availability is critical for maize production. Maize uses an increasing amount of water every day from about 30 days before silking until fertilization, when water uptake peaks before steadily declining. Therefore, maize is most susceptible to stress from lack of moisture during the silking and early grain fill stages of its reproductive cycle. By United States standards, it has been determined that 190 kilograms of nitrogen (N), 39 kilograms of phosphorus (P), and 196 kilograms of potassium (K) are required per hectare to produce 150 bushels of maize grain (Smith 1995). Rapid N, P, and K uptake begins about 25 days after emergence, and by the silking, or flowering, stage, nutrient uptake is 50-60% complete.

In the Kakamega District in Western Kenya, it is recommended to plant shortly after the onset of the rain season at depths between 2.5-5.0 cm to protect the seed against rodents and provide adequate moisture contact (Salasya et al., 1998). The recommended spacing for planting is 75 x 30 cm, resulting in a density of 44,800 plants per hectare. Maize should be harvested when the leaves and husk are dry and the moisture content of the grain is less than 35%, best indicated by a black layer at the base of the kernel.

Nitrogen (N) is typically the nutrient of most concern because is has a strong influence on cereal crop yields. It is most abundantly found in the N_2 gaseous form, 99.4% of which is found in the earth's atmosphere (Havlin et al., 2005). Plants take up N in the form of NH_4^+, a result of mineralization, and NO_3^-, a result of nitrification. One to six percent of plants are nitrogen by weight. It can be stored in the soil on the cation exchange complex (CEC) in the form of NH_4^+, but in the forms of NO_3^- and NO_2^-, it has the potential to leach out of the root zone of the soil or undergo denitrification when it is then lost to the atmosphere in the forms of N_2O, NO, and N_2.

Nutrient Management

Nutrients in the soil system may or may not be available to plants, or they may leave the soil system before plants utilize them. Therefore, proper nutrient management is a critical component to any crop production. Studies by Kihanda et al. (2006) observed a strong relationship between high rainfall and high crop yields, as water is needed to release nutrients to plant roots. However, water also contributes to nutrient leaching. When water percolation is high, N lost from leaching may also be high (Smith, 1995); this effect is most significant in soils with a high percentage of sand (van Es et al., 2006). N can also be lost from denitrification as a result of prolonged anaerobic conditions (Smith, 1995). When N is applied to the soil surface, it may volatilize or be tied-up by decay microorganisms. Studies by van Es et al. (2006) found that high quantities of residual N lead to high amounts of N leaching, specifically during time periods that follow dry growing seasons.

Differences among maize plants under various organic resources were noticed within two weeks of emergence in a study by Mtambanengwe et al. (2006), indicating the importance of N availability early in the growth stages of maize. Their study indicated a strong correlation between early and consistent supply of N and grain yield. Especially under sandy soils, maize biomass accumulation is hindered when high quality organic fertilizers, or fast-N-releasing inorganic fertilizers are not available, resulting in decreased gain yields. Salasya et al. (1998) also indicated the importance for P fertilizers. It was recommended that in the Kakamega District, all of the P and half of the N fertilizer be applied at the time of planting, and the remaining N fertilizer should be applied six weeks after plant germination when the plants are approximately knee-high.

Carbon (C) concentrations in soil also have an affect on N availability. Soil samples surveyed by Makokha et al. (2001) found high quantities of soil organic C (3-4%), reflecting high levels of applied soil organic matter (SOM), which can likely be correlated to low levels of N mineralization. For purposes of N release, a low C:N ratio (10-15) is preferred, allowing the N to be mineralized instead of synthesized by microbial organisms.

Manure Fertilizers

In manure, between 50 and 75% of total N is organic ($R\text{-}NH_2$) and needs to undergo mineralization before it becomes available for plants; the remaining 25 to 50% is NH_4^+, which is highly susceptible to volatilization (Havlin et al., 2005). Ammonium-N (NH_4^+) is immobilized in the soil upon application to the soil surface. The degree of immobilization may be increased by the addition of bedding materials with a high C:N ratio compared with that of the manure (Thomsen, 2005). Increasing amounts of SOM within the soil provide more exchange sites on the CEC for N immobilization.

Both C and N cycles are closely connected within the soil microbial community, as studies have shown that a linear relationship exists between net C concentrations and N mineralization and immobilization (Mallory and Griffin, 2007). Studies by Makokha et al. (2001) showed that cattle manure, in comparison to swine and poultry, showed the highest C:N ratio and poultry manure showed the lowest C:N ratio. In terms of N release, a low C:N ratio is preferred because it allows for the highest rate of decomposition. When examining organic fertilizers by N content, Mtambanengwe et al. (2006) found cattle manure to be of a medium quality in comparison to other organic materials. Studies showed that when dealing with an organic material that is low in N content, a lower application rate leads to higher yields than a high application rate due to the decreased time of N immobilization. It was also found that N availability and release from low quality organic materials can be improved with the application of an inorganic N fertilizer.

Mineralization and N recycling begin as soon as the manure is incorporated into the soil. The rate of mineralization varies among N sources, but the rate is highest at application and decreases with time (Havlin et al., 2005). The risk of N volatilization increases with increasing pH, is higher on the soil surface as compared to when N is incorporated, increases with increasing temperature and with the presence of crop residue. Volatilization has the potential of causing 15 to 40% loss of total N in the soil.

In comparing organic fertilizers with inorganic fertilizers, study results are mixed. Kihanda et al. (2004) found that, over a seven year trial, Kenyan maize yields were similar in plots treated with goat manure to plots treated with inorganic fertilizer. However, studies by Mallory and Griffin (2007) found that inorganic N applications became available more quickly than N applications from manure.

Manure Storage

The N pool in manure also declines during storage and handling (Ohio Livestock Manure Management Guide, 2006). Thus, proper management of manure to minimize N loss is crucial. The consistency of the manure (liquid, slurry, semi-solid, or solid) must also be considered when developing a management plan. Solid manure storage allows for low nutrient loss, and nutrient loss is even less if the storage is covered. Slurry pits or tanks, below building pits, and earthen holding ponds have low to moderate nutrient loss. Treatment lagoons have a high loss of N due to volitalizaiton.

A study by Sommer et al. (2007) showed that N mineralization during storage is dependent upon the reduction of SOM, which can be observed by the production of CO_2 and CH_4 during storage. These reactions are in turn affected by temperature and the presence of an adapted microbial community in pre-stored manure slurry during the 100-200 day slurry incubation. Results showed that CH_4 production was not significant below 15ºC but became significant at 20ºC relative to CO_2 production. As a result, little N was mineralized during storage at 10ºC for both cattle and pig slurry as well as at 15ºC for cattle slurry. At 15ºC for pig slurry and at 20ºC for both pig and cattle slurry, 80% of organic N was mineralized. When manure is processed in a anaerobic digester for biogas production, there was no maize yield differences between processed swine manure and raw swine manure (Loria et al, 2007).

Manure Application Timing

Application timing is a crucial component to maximizing N use efficiency. Management of manure fertilizers is much more difficult than that of mineral fertilizers, primarily because manure and other organic fertilizers are affected by the handling during storage and application as well as the timing of incorporation and distribution (Thomsen, 2005). A study by Maroko et al. (1998) showed a linear relationship between soil nitrate availability at the time of planting and maize yields. Autumn applications increase N loss through the soil system, in comparison with later applications that lead to increased crop utilization of N (Thomsen, 2005).

Leaching potential may change with different temperature regimes experienced throughout seasons: late fall and spring applications, when soil temperatures are low, may have a different effect on N loss as compared to an early fall application (van Es et al., 2006). Czapar et al. (2007) recommend that if manure is applied in the fall, application should not occur until the soil is below 50ºF (10ºC) and the nitrogen fertilizer should be applied with a nitrification inhibitor to minimize nitrification. Other contributing factors to the rate of N loss include soil type, soil temperature and moisture regimes, crop uptake potential, and precipitation corresponding with percolation (van Es et al., 2006). In the study conducted by Loria et al. (2007), differences between maize yields among different site locations were attributed to N loss potential from a late fall application as opposed to a spring application at other sites. Soil samples indicated that rapid nitrification occurred with application timings.

Long Term Yield Effects from Manure

Studies have shown that manure can have positive long-term effects on maize yield. In a study by Mallory and Griffin (2007), the long-term effects that manure applications have on soil characteristics and subsequently N availability from recently added N were examined. Results showed that when no new N was added, net mineralization in soils with a history of organic management was twice that of soils with a history of industrial management. When N was added, results showed a strong interaction between the type of N added and the historical management of the soil. Soils that were historically organic amended showed larger soil C and N stocks, C and N pools that were more readily available, and more microbial biomass and activity as compared to soils that were not historically organic amended. Studies by Kihanda et al. (2006) showed that when manure was applied from seven consecutive years, crop yields increased and then stabilized. When manure was only applied for four consecutive years, yields remained high for seven or eight years before decreasing. Results concluded that manure residual could sustain crop yields for at least seven years.

Methods

Post-Harvest (September 2007):

- Farmyard manure will be applied to half of field plots at each of the four location sites, as outlined on field map, at a rate of 8 t/ha. Each plot will be marked with two flags, one in the center of the width side of the plot along the perimeter.
- One manure sample of each type of manure applied to any one plot (diary, poultry, and composite) will be analyzed for N,P,K, and moisture content. Samples will be kept frozen or refrigerated between sampling and analysis.
- Daily rainfall and daily maximum and minimum temperatures will begin to be recorded.

Pre-Planting (Early March 2008):

- Farmyard manure will be applied to the remaining half of field plots at each of the four location sites, as outlined on field map, at a rate of 8 t/ha. Each plot will be marked with two flags, one in the center of the width side of the plot along the perimeter.
- One manure sample of each type of manure applied to any one plot (diary, poultry, and composite) will be analyzed for N,P,K, and moisture content. Samples will be kept frozen or refrigerated between sampling and analysis.

Planting (Mid-March 2008):

- Maize variety KSTP 94 will be planted uniformly in all plots with a spacing of 30 cm by 75 cm, at least one week after the manure was applied. The layout (Fig. 1) will be replicated at four locations, which were selected on the basis of similarity of soil type.

Post Emergence:

- Stand counts will be determined for each plot by counting the total number of plants that have emerged from the middle two rows of each plot.

Initial Silk Stage:

- Plant height will be measured for 10 plants from the inner two rows of each plot by using a meter stick to measure the distance from the ground at the base of the plant to from the base of the plant to the collar of the ear leaf. The average plant height will be determined for each plot to be used in statistical analysis.
- A leaf color chart will be used in maximum sunlight to measure the color (an indicator of the N content within the plant) of the ear leaf for 10 separate plants from the inner two rows of each plot. Half a unit may be recorded if the ear leaf color is between two ranges (eg 6.5). The average color measurement will be determined for each plot to be used in statistical analysis.
- 10 separate ear leaves will be sampled without leaf collars from the inner two rows of each plot to be analyzed for total N concentration at the early flowering stage. Leaves will be combined to form one sample for each plot. Samples will be dried at 60 degrees Celsius in an oven dryer. Samples will be analyzed for total N and total C concentrations.
- 5 soil samples will be collected from each plot, each at two depths (0-6" and 6-12"). Samples will be combined to form one 0-6" sample and one 6-12" sample for each plot. Samples will be dried using a soil oven at 60 degrees Celsius. Samples will be analyzed for total N and total C concentrations.

Harvest:

- Stand counts will be determined again for each plot by counting the total number of plants that have developed an ear from the middle two rows of each plot.

- Gain yield will be calculated for each plot by weighing the shelled corn collected from 10 feet of the inner two rows of each plot. Yields will be converted to 14% moisture content.
- Moisture content of plants taken for calculated grain yield will be determined by
- Plant biomass will be determined by weighing all above ground plant biomass, minus the maize ear and husk, of plants taken for calculated grain yield for each plot.
- Maize yield results will be compared to yields from one farm using chemical fertilizers and farm not using any fertilizers.

Post-Harvest:

- Statistical analyses (ANOVA, t-tests, LSD) using paired t-tests will be done to compare treatment means.

Figures

<table>
<tr><td>4 rows of maize; 3 x 7 meters;
manure application after harvest</td><td>4 rows of maize; 3 x 7 meters;
manure application before planting</td></tr>
<tr><td colspan="2">4.5 meter separation; filled with general maize</td></tr>
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Fig. 1. Aerial layout of plot plan, replicated at four locations.

Anticipated Outcomes

The objective of the project is to compare maize production and yields (determined by weight of shelled maize) of plots that receive manure fertilizer during the post-harvest season to those that receive manure fertilizer shortly before planting. It is hypothesized that the plots receiving manure fertilizer closer to the time of planting produce significantly higher crop yields than those that receive the manure application after harvest. Results will be analyzed and presented in such a way that subsequent management recommendations can be easily communicated to the farming community. Results will be used to prepare a "fact sheet" that can be used by extension agents to transfer the technology.

Anticipated Pitfalls

Communication is continually improving between myself and the individuals at the field sites who are helping with the project. However, there is still a potential for communication breakdown cross-continent, through both technical difficulties and from the slight language barrier between the different English dialects between the United States and Kenya. There were initial communication breakdowns at the beginning of the project, resulting in manure samples being lost and not analyzed. However, communication has drastically improved and risk of communication affecting the successful completion of the project is diminishing. There are also additional variables related to variability in rainfall and temperature that would have significant effects on the project outcome. All four research sites are within close proximity of each other, so all locations should be equally affected by this variability. Additionally, daily temperatures and rainfall will be recorded so this variability can be taken into consideration. There are also potential concerns for pests and rodents affecting research plots, and the need for a fence will be evaluated.

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Budget

Total Amount: *$4470*

By Item:	Assistant's Salary:	$300
	Housing and meals for 3 weeks:	$1050
	International cell phone, calling cards:	$100
	Manure, seeds, field markers, etc:	$200
	Lab analysis:	$250
	Airfare:	$2200
	Transportation during 3 weeks:	$300
	Bicycle (for independent transportation):	$70